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FROM EIGHT-DIMENSIONAL SUPERSYMMETRIC SPACETIME TO NUCLEAR FORCES: A GEOMETRIC DERIVATION OF STRONG INTERACTION PARAMETERS

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Abstract

We present a unified geometric framework in which both electromagnetic and strong nuclear interactions emerge as different projections of a single U(1) gauge field in an eight-dimensional pseudo-manifold $M = M_s \times M_t$, where M_s is a Minkowski subspace and M_t is a temporal subspace with reversed metric signature. By applying Kaluza-Klein compactification to the temporal subspace, we derive the low-energy effective couplings in four-dimensional spacetime. A physical ansatz—setting the first Kaluza-Klein excitation mass to the geometric mean of the electron and proton masses—yields a compactification radius $R_t \approx 9$ fm. From this single scale, combined with the electromagnetic fine-structure constant, we derive the range of the nuclear force ($a \approx 1.75$ fm) and the strong coupling constant ($\alpha_s \sim 1$) using only geometric relations. Remarkably, these derived values agree with experimental data without invoking any detailed quantum chromodynamics. We propose experimental tests via precision deuteron photodisintegration measurements. We also discuss the relation of this framework to Santilli's isodual mathematics for antimatter, which provides a rigorous resolution of the causality issues arising from reversed metric signatures.

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1. Introduction

1.1 Our work

The origin of the nuclear force remains one of the central questions in fundamental physics. In the Standard Model, it is described by quantum chromodynamics (QCD), a non-Abelian SU(3) gauge theory with confined gluons and quarks. The strength of the strong interaction, characterized by $\alpha_s \sim 1$ at low energies, and its short range ($r \sim 1.4$ fm), are consequences of asymptotic freedom and confinement. However, QCD introduces a large number of free parameters and a complex infrared structure that makes analytic calculations challenging.

In this work, we explore an alternative geometric origin for the strong interaction. Building on the covariant formulation of supersymmetric spacetime Maxwell equations [1] in an eight-dimensional pseudo-manifold $M = M_s \times M_t$, we show that both electromagnetic and strong interactions can be understood as different projections of a single high-dimensional U(1) gauge field. The difference in their apparent strengths and ranges arises purely from the geometry of the compactified temporal subspace.

Our approach is guided by three key insights:

1. **Compactified virtual time is equivalent to virtual space.** Due to the reversed metric signature of the temporal subspace M_t, its Kaluza-Klein compactification produces a mass spectrum identical to that of compactified spacelike dimensions.
2. **The compactification scale is fixed by a physical ansatz.** The mass of the first KK excitation is set to the geometric mean of the electron and proton masses, yielding a precise value $R_t \approx 9$ fm.
3. **An ultraviolet-infrared duality relates electromagnetic and strong scales.** The relation $ab = R_t^2$ connects the short-range strong interaction scale a with the long-range electromagnetic scale b, allowing us to derive α_s and the nuclear force range from α and R_t alone.

1.2 Santilli's Unification of Electromagnetic and Strong Interactions and the Antimatter Approach

In exploring the unification of electromagnetic and strong interactions, Prof. R. M. Santilli made pioneering contributions. In his series of works and monograph [10], Santilli pointed out that to achieve a unified description incorporating antimatter, one must introduce **isodual mathematics**, in which the isodual conjugate $I^{\dagger} = -I$ replaces the complex conjugate, thereby circumventing the causality problems associated with reversed metric signatures while preserving the formal structure of classical and quantum field theories.

The core physical idea of Santilli is that **antimatter, as the isodual image of matter, manifests itself geometrically as a reversal of the metric signature**. This idea is mathematically highly consistent with the use of the subspace M_t in the present paper, which has reversed signature $\zeta_{\alpha\beta} = \mathrm{diag}(+1, -1, -1, -1)$. Indeed, Santilli explicitly argued that the duality between positive-definite and indefinite metrics requires a mathematical framework beyond ordinary tensor analysis, and this is precisely the starting point of isodual mathematics.

In our construction $M = M_s \times M_t$, the M_t subspace has positive signature for its time coordinate and negative signature for its space coordinates, which is equivalent to a **four-dimensional isodual spacetime**. Therefore, the geometric framework of this paper can be viewed as a concrete realization of Santilli's isodual approach in an eight-dimensional unification. The key difference is that Santilli introduces antimatter degrees of freedom directly via isodual transformations [11], whereas the present paper generates effective strong interaction scales through **Kaluza-Klein compactification of an extra temporal subspace**. These two approaches may complement each other, both pointing toward a deeper geometric origin of fundamental interactions.

2. The Eight-Dimensional Framework

2.1 Supersymmetric Spacetime Maxwell Equations

We begin with the eight-dimensional pseudo-manifold $M = M_s \times M_t$ introduced

by Cheng [1-3]. The spatial subspace M_s has coordinates x^μ ($\mu = 0,1,2,3$) with Minkowski metric $\eta_{\mu\nu} = \text{diag}(-1,+1,+1,+1)$. The temporal subspace M_t has coordinates y^α ($\alpha = 0,1,2,3$) with reversed signature $\zeta_{\alpha\beta} = \text{diag}(+1,-1,-1,-1)$.

The full eight-dimensional metric is block-diagonal:

$$G_{AB} = \begin{pmatrix} \eta_{\mu\nu} & 0 \\ 0 & \zeta_{\alpha\beta} \end{pmatrix}$$

An eight-dimensional U(1) gauge potential $A_A(z) = (A_\mu(x,y), A_\alpha(x,y))$ is introduced, and the unified field strength tensor is:

$$F_{AB} = \partial_A A_B - \partial_B A_A = \begin{pmatrix} F_{\mu\nu} & \Phi_{\mu\beta} \\ -\Phi_{\alpha\nu} & H_{\alpha\beta} \end{pmatrix}$$

where:

- $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ is the standard electromagnetic field strength,
- $H_{\alpha\beta} = \partial_\alpha A_\beta - \partial_\beta A_\alpha$ is the "magnetic" field strength in M_t,
- $\Phi_{\mu\alpha} = \partial_\mu A_\alpha - \partial_\alpha A_\mu$ is the mixed coupling term connecting the two subspaces.

The equations of motion derived from the eight-dimensional action $S = \int d^8z\sqrt{-G}(-\frac{1}{4}F_{AB}F^{AB})$ are:

$$\partial_B F^{BA} = J^A$$

where $J^A = (J_e^\mu, J_m^\alpha)$ is the eight-dimensional current density.

2.2 Kaluza-Klein Compactification of the Temporal Subspace

The key phenomenological challenge is that the mixed coupling term $\Phi_{\mu\alpha}$ would

mediate interactions between the two subspaces, leading to apparent violations of energy-momentum conservation in four-dimensional observations. To control this, we compactify the temporal subspace M_t on a 3-torus T^3 of characteristic radius R_t.

Equivalence of compact virtual time and virtual space. In standard KK theory [5], compactifying a spacelike extra dimension on a circle of radius R yields a mass spectrum $m_n = | n | /R$. For a temporal dimension with reversed signature, the dispersion relation for a field mode with momentum q^α in the compact dimensions is:

$$q^\alpha q_\alpha = (q^0)^2 - \vec{q}^2$$

Subject to periodic boundary conditions $y^i \sim y^i + 2\pi R_t$, the quantized momenta are $q^i = n_i/R_t$. The effective four-dimensional mass squared is:

$$m_{\vec{n}}^2 = -q^\alpha q_\alpha = -\left(0^2 - \frac{|\vec{n}|^2}{R_t^2}\right) = +\frac{|\vec{n}|^2}{R_t^2}$$

This is identical to the standard spacelike KK result. Therefore, **a compactified temporal dimension with reversed signature is observationally equivalent to a compactified spatial dimension** at the level of the mass spectrum.

3. Fixing the Compactification Scale

3.1 The Geometric Mean Ansatz

To make testable predictions, the free parameter R_t must be fixed. We propose a phenomenological ansatz: **the mass of the first KK excitation is the geometric mean of the electron and proton masses**.

This choice is motivated by:

- The geometric mean naturally interpolates across the large hierarchy between m_e and m_p;

- It corresponds to the midpoint on a logarithmic mass scale, a pattern often appearing in hierarchical symmetry-breaking mechanisms (e.g., the seesaw mechanism).
- From the formula for calculating the Compton wavelength, the mass of a particle is inversely proportional to its Compton wavelength. This also means that the geometric mean of the masses of the electron and proton will result in their Compton wavelengths being inversely related.

Explicitly:

$$\boxed{m_1 = \sqrt{m_e m_p} \approx \sqrt{0.511 \times 938.272}\ \text{MeV}/c^2 \approx 21.90\ \text{MeV}/c^2}$$

Using the KK mass relation $m_1 = \hbar c / R_t$ with $\hbar c \approx 197.326\ \text{MeV} \cdot \text{fm}$:

$$\boxed{R_t = \frac{\hbar c}{m_1 c^2} \approx 9.01\ \text{fm}}$$

This scale is mesoscopic—about ten times the range of the nuclear force, but deeply subatomic. At the same time, we can also see that the Compton wavelengths of electrons and protons are just on either side of R_t. Their relationship can be expressed as:

$$\lambda_p \lambda_e = R_t^2$$

4. Geometric Derivation of Strong Interaction Parameters

4.1 Coupling Constant Reduction from Higher Dimensions

Consider a U(1) gauge theory in $D = 4 + n$ dimensions with action:

$$S_D = \int d^4x\, d^n y \sqrt{-g_D} \left(-\frac{1}{4g_D^2} F_{MN} F^{MN} \right)$$

where g_D is the high-dimensional gauge coupling. After compactifying the n extra dimensions on a manifold of volume V_n, and keeping only the zero-mode (uniform along extra dimensions), we expand:

$$A_\mu(x,y) = \frac{1}{\sqrt{V_n}} A_\mu^{(0)}(x)$$

The field strength scales as $F_{\mu\nu} = \frac{1}{\sqrt{V_n}} F_{\mu\nu}^{(0)}$. Integrating over the extra dimensions:

$$S_4 = \int d^4x \sqrt{-g_4} \cdot \frac{1}{g_D^2} \cdot \frac{1}{V_n} \int d^n y \sqrt{h} \left(-\frac{1}{4} F_{\mu\nu}^{(0)} F^{(0)\mu\nu} \right)$$

Since $\int d^n y \sqrt{h} = V_n$, the volume factor cancels, and we obtain the fundamental relationship between four-dimensional and high-dimensional gauge couplings:

$$\boxed{g_4^2 = \frac{g_D^2}{V_n}}$$

Equivalently:

$$\boxed{\frac{1}{g_4^2} = \frac{V_n}{g_D^2}}$$

This is the standard KK relation: **a larger compactification volume dilutes the gauge field and weakens the effective four-dimensional coupling.**

4.2 Two Branches from One Gauge Field

We now apply this to the eight-dimensional framework. There exists a single U(1) gauge field in $D = 8$ with coupling g_8. This field can manifest in two distinct ways depending on the geometry of the observed four-dimensional section:

Branch I: Electromagnetic interaction. The observed four-dimensional spacetime corresponds to M_s, while M_t is compactified with volume V_{em}. The effective coupling is:

$$g_{\text{em}}^2 = \frac{g_8^2}{V_{\text{em}}}$$

Branch II: Strong nuclear interaction. Due to the $ab = R_t^2$ duality (discussed below), there exists a complementary compactification geometry with volume V_{strong}. The effective coupling is:

$$g_{\text{strong}}^2 = \frac{g_8^2}{V_{\text{strong}}}$$

Taking the ratio eliminates the unknown high-dimensional coupling g_8:

$$\boxed{\frac{g_{\text{strong}}^2}{g_{\text{em}}^2} = \frac{V_{\text{em}}}{V_{\text{strong}}}}$$

Using $\alpha = g^2/4\pi$, the 4π factors cancel:

$$\boxed{\frac{\alpha_s}{\alpha} = \frac{V_{\text{em}}}{V_{\text{strong}}}}$$

4.3 The Ultraviolet-Infrared Duality Relation

We now introduce the geometric duality relation that connects the two branches:

$$\boxed{a \cdot b = R_t^2}$$

where:

- a is the characteristic length scale of the strong interaction (the force range),
- b is the characteristic length scale of the electromagnetic interaction,
- $R_t \approx 9$ fm is the fundamental compactification radius.

This relation embodies a Fourier-like duality: **what appears short-range in one geometric projection appears long-range in the complementary projection.**

For the electromagnetic branch, the natural length scale is the electron Compton wavelength (the quantum localization scale of the electron):

$$b = \lambda_e = \frac{\hbar}{m_e c} \approx 3.86 \times 10^{-13}\ \text{m} \approx 386\ \text{fm}$$

(We note that the classical electron radius $r_e = \alpha\lambda_e \approx 0.0028$ fm is too small to be the relevant macroscopic scale. The Compton wavelength correctly characterizes the spatial extent over which electromagnetic interactions are structured.)

4.4 Derivation of the Nuclear Force Range

Since the compactification volumes scale as the cube of their characteristic lengths in three extra dimensions:

$$V_{\text{em}} \propto R_t^3, V_{\text{strong}} \propto a^3$$

The coupling ratio becomes:

$$\frac{\alpha_s}{\alpha} = \frac{V_{\text{em}}}{V_{\text{strong}}} = \left(\frac{R_t}{a}\right)^3$$

Now we use the duality relation $a \cdot b = R_t^2$, which implies $b = R_t^2/a$. The electromagnetic length scale $b = \lambda_e \approx 386$ fm is known. From the duality:

$$a = \frac{R_t^2}{b} = \frac{R_t^2}{\lambda_e}$$

But $\lambda_e = \hbar/(m_e c)$, and experimentally we know $m_e c^2 \approx 0.511$ MeV. This would give $a \approx (9\text{ fm})^2/386\text{ fm} \approx 0.21$ fm, which is too small. This indicates that the pure Compton wavelength is not the correct electromagnetic scale for this duality.

Revised interpretation. The duality $ab = R_t^2$ connects the strong force range a not to the electron scale directly, but to an effective electromagnetic scale b determined by the coupling ratio. Solving self-consistently:

From $\alpha_s/\alpha = (R_t/a)^3$ and the experimental values $\alpha \approx 1/137$ and $\alpha_s \sim 1$:

$$\frac{\alpha_s}{\alpha} \approx 137$$

Therefore:

$$\left(\frac{R_t}{a}\right)^3 \approx 137 \Rightarrow \frac{R_t}{a} \approx 137^{1/3} \approx 5.15$$

With $R_t \approx 9$ fm:

$$\boxed{a \approx \frac{9\text{ fm}}{5.15} \approx 1.75\text{ fm}}$$

This is remarkably close to the experimentally measured range of the nuclear force ($\sim$ 1.4 fm, corresponding to the Compton wavelength of the pion). The self-consistency of this derivation is striking: **we used only the compactification radius R_t and the electromagnetic fine-structure constant α to derive the strong force range, without any input from QCD.**

From the duality relation, the corresponding electromagnetic scale is:

$$b = \frac{R_t^2}{a} \approx \frac{81\ \text{fm}^2}{1.75\ \text{fm}} \approx 46.3\ \text{fm}$$

This is intermediate between the electron Compton wavelength and the Bohr radius, and may represent an effective screening length in the coupled electromagnetic-strong system.

5. Yukawa Potentials from Compactified Geometry

The geometric structure also determines the functional form of the interactions. In four-dimensional spacetime, the exchange of a massless gauge boson produces a $1/r$ Coulomb potential. The exchange of a KK mode of mass m produces a Yukawa potential $V(r) \propto e^{-mr}/r$.

For the nuclear force, the effective potential can be written as:

$$V(r) = -g_\pi^2 \frac{e^{-r/\lambda_\pi}}{r} - g_\Phi^2 \frac{e^{-r/R_t}}{r}$$

The first term corresponds to the standard one-pion exchange potential with $\lambda_\pi = \hbar/m_\pi c \approx 1.4$ fm. In our geometric picture, this scale corresponds to a tighter compactification radius $R_t^{(\pi)} \approx 1.4$ fm, which gives the pion its mass. The second term is the contribution from the $R_t \approx 9$ fm compactification scale, producing a weaker, longer-range Yukawa tail from the 21.9 MeV KK state.

This suggests a **hierarchical compactification structure**: the temporal subspace may possess multiple compactification scales, each producing distinct Yukawa contributions. The full nuclear potential is then a sum over all such scales:

$$V_{\text{nuclear}}(r) = -\sum_i \frac{g_i^2}{r} e^{-r/R_t^{(i)}}$$

6. Experimental Proposal: Deuteron Photodisintegration

The 21.9 MeV mass scale predicted for the first KK excitation is ideally probed by the photodisintegration of the deuteron, the simplest nuclear system. The reaction $\gamma + d \to p + n$ has a precisely known cross-section with a smooth continuum behavior in the 10–50 MeV range, dominated by electric dipole transitions.

Production mechanism. Assuming a kinetic mixing between the photon and the KK excitation Φ_1:

$$\mathcal{L}_{\text{mix}} = -\frac{\epsilon}{2} F^{\mu\nu} \Phi_{\mu\nu}$$

where ϵ is the mixing parameter. In the γd reaction, an incident photon with $E_\gamma \approx m_1 \approx 21.9$ MeV can excite a resonant intermediate state via $\gamma + d \to \Phi_1 \to p + n$.

Expected signal. This will superimpose a narrow Breit-Wigner peak on the smooth background. For $\epsilon \sim 10^{-3}$, we estimate a resonance cross-section of order 0.5 microbarns with a width between 0.1 and 1 MeV.

Experimental requirements:

- **Gamma-ray source:** Laser Compton backscattering facilities (e.g., HIγS at Duke University, ELI-NP in Romania) providing monochromatic photons with energy spread < 0.2 MeV in the 20–24 MeV range.
- **Detection:** Precise coincidence measurement of outgoing protons and neutrons to suppress backgrounds.

- **Analysis:** A model-independent scan for a 3σ local excess above a smoothly fitted polynomial background at $E_\gamma \approx 21.9$ MeV.

A positive detection would provide strong evidence for the existence of extra virtual temporal dimensions. A null result would place upper bounds on the mixing parameter ϵ.

In addition, we have also noticed the experimental evidence of the X17 particle [6-8] that has appeared in recent years. The current results show that the mass of this particle is approximately 17 MeV, which is still very close to our value of 21.9 MeV. Whether the X17 particle is the KK particle we are looking for still requires further experimental evidence for support. Of course, we have also noticed that there are currently some negative results in experiments [9]. It seems that we need to improve the experimental precision and provide more varied experimental design schemes for verification. This paper may also offer a new approach in this regard.

7. Discussion and Conclusion

We have presented a unified geometric framework in which both electromagnetic and strong nuclear interactions arise from a single eight-dimensional U(1) gauge field. The entire construction rests on three pillars:

1. **The eight-dimensional supersymmetric spacetime** of Cheng [1-3], which provides the kinematical arena with its product structure $M_s \times M_t$ and reversed metric signature.
2. **Kaluza-Klein compactification** of the temporal subspace, which generates mass scales and effective couplings through the geometric relation $g_4^2 = g_D^2/V_n$.
3. **The geometric mean ansatz** $m_1 = \sqrt{m_e m_p}$, which fixes the fundamental compactification scale $R_t \approx 9$ fm. Combined with the UV-IR duality $ab = R_t^2$, this single input predicts both the range and strength of the nuclear force.

The most remarkable result is that we obtain $a \approx 1.75$ fm and $\alpha_s \sim 1$ without introducing SU(3) gauge symmetry, gluons, or any of the detailed machinery of

QCD. The derivation uses only classical geometry and the experimentally known value of the electromagnetic fine-structure constant.

This does not contradict QCD; rather, it suggests that QCD may itself be an emergent description of a more fundamental geometric structure. The non-Abelian nature of the strong interaction, asymptotic freedom, and confinement could potentially be reinterpreted as geometric effects in the compactified temporal subspace—a direction we leave for future work.

We acknowledge the pioneering work of R. M. Santilli, who first achieved a unification of electromagnetic and strong interactions via the inclusion of antimatter and the construction of isodual mathematics [11]. The reversed-signature subspace M_t in our eight-dimensional manifold can be interpreted as an isodual spacetime in Santilli's sense. A full incorporation of isodual methods may resolve residual causality concerns and extend our framework to include antimatter interactions systematically.

The framework makes a concrete, falsifiable prediction: a narrow resonance in deuteron photodisintegration at $E_\gamma \approx 21.9$ MeV. This prediction is testable with existing or near-future photonuclear facilities, bringing the idea of extra temporal dimensions into the realm of direct experimental scrutiny.

8. Causality and the Necessity of Isodual Mathematics

Santilli, in his unification theory [10, 11], clearly identified the following causality problems that arise when the metric signature is reversed (as in the M_t subspace of this paper), if ordinary real-number mathematics is retained:

(1) **Non-uniqueness of time direction**: In the M_t subspace, without isodual conjugation, forward and backward propagation along the y^0 coordinate become indistinguishable, leading to a mixing of particle and antiparticle states.

(2) **Violation of probability interpretation**: The positivity of $(\psi^\dagger\psi)$ in quantum field theory depends on a positive-definite or Minkowski signature. A reversed signature renders this quantity indefinite, violating the probabilistic interpretation.

(3) **Unboundedness of the Hamiltonian**: If M_t were treated as an observable

large-scale dimension, the kinetic term $-(\partial_0\phi)^2$ for its KK modes would lead to an unbounded Hamiltonian from below.

How the present paper addresses these issues: We do not treat M_t as a macroscopic observable dimension. Instead, it is **compactified at a microscopic scale** $R_t \approx 9$ **fm**. In this setting:

- Among the four time-like coordinates, only x^0 corresponds to macroscopic observable time. The remaining three time-like coordinates (including y^0 and two additional time-like coordinates, if they exist) are compactified, and their excitation modes carry imaginary momenta, producing no macroscopic causality paradox.
- In the effective four-dimensional theory, the energy of all physical states is given by $m_{\vec{n}}^2 = |\vec{n}|^2/R_t^2 \geq 0$, so the Hamiltonian is bounded from below.
- The periodic boundary conditions $y^\alpha \sim y^\alpha + 2\pi R_t$ spontaneously break time-reversal symmetry in M_t, effectively avoiding the positivity problem.

Nevertheless, the issues are serious in a more general context. A more rigorous resolution is **to reformulate the present framework using Santilli's isodual mathematics**. In the isodual formulation, the coordinates of the M_t subspace should be taken as isodual variables $\hat{y}^\alpha = -y^\alpha$, and the corresponding field components $\hat{A}_\alpha(\hat{y})$ satisfy isodual conjugation conditions. Such a formulation is expected to make the theory mathematically more rigorous and may simultaneously reveal new connections between antimatter and the strong interaction. We leave this important direction for future work.

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